

Proton Structure from HERA to LHC

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The kinematic region covered by the LHC experiments probes low values of Bjorken- x . At the scale relevant for W and Z production the central rapidity region covers $10^{-3} < x < 10^{-1}$, for $\sqrt{s} = 7$ TeV. This means that it is the HERA data which give the most insight into the behaviour of parton distribution functions (PDFs) for the early phase of running at the LHC. The H1 and ZEUS experiments are combining their data so as to provide a legacy of HERA results. The present status of the data combinations and the impact of these data on our knowledge of parton distribution functions is explored.

1 Introduction

H1 and ZEUS have combined various sub-sets of their data. The combination of inclusive cross section data from HERA-I and the PDF fit based on these data are already published [1]. In 2010 further data have been combined and PDF fits to the augmented data sets have been made available in preliminary form. In Sec. 2.1 results from the published combination are reviewed. In Sec. 2.2 results from a combination of $F_2^{e\bar{e}}$ data are presented and their impact on predictions for W and Z production at the LHC discussed. In Sec. 2.3 results from the combination of inclusive cross section data taken at lower proton beam energies are discussed. Finally, in Sec. 2.4 an updated combination of all inclusive data from HERA-I and HERA-II running is shown and predictions for the LHC W and lepton asymmetries, from a PDF fit to these data, are presented.

2 Results

2.1 Inclusive data from HERA-I running

The inclusive cross section data, from the HERA-I running period 1992-2001, for Neutral Current (NC) and Charged Current (CC), e^+p and e^-p scattering have been combined [1]. The combination procedure pays particular attention to the correlated systematic uncertainties of the data sets such that resulting combined data benefits from the best features of each detector. The combined data set has systematic uncertainties which are smaller than its statistical errors and the total uncertainties are small (1 – 2%) over a large part of the kinematic plane. The combined data is compared to the separate input data sets of ZEUS and H1 in Fig. 1.

These data are used as the sole input to a PDF fit called the HERAPDF1.0 [1]. The motivations for performing a HERA-only fit are firstly, that the combination of the HERA data yields a very accurate and consistent data set such that the experimental uncertainties on the

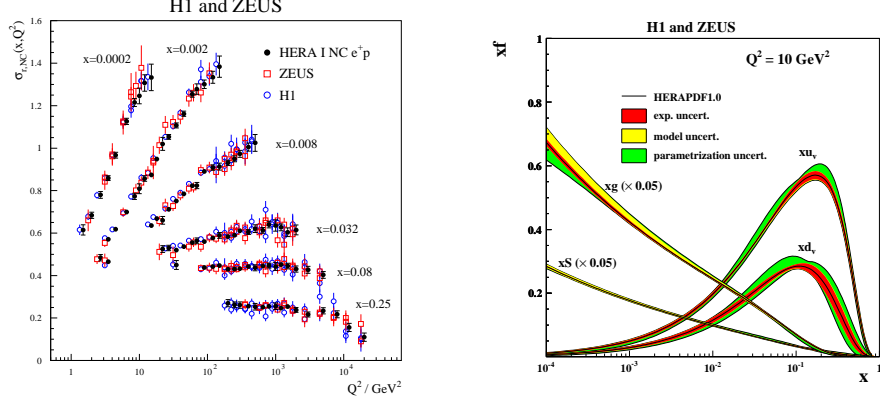


Figure 1: Left: HERA combined data points for the NC e^+p cross-section as a function of Q^2 in selected bins of x , compared to the separate ZEUS and H1 data sets input to the combination. Right: Parton distribution functions from HERAPDF1.0; xu_v , xd_v , $xS = 2x(\bar{U} + \bar{D})$ and xg at $Q^2 = 10 \text{ GeV}^2$.

PDFs may be estimated from the conventional χ^2 criterion $\Delta\chi^2 = 1$. Global fits which include data sets from many different experiments often use inflated χ^2 tolerances in order to account for marginal consistency of the input data sets. Secondly, the HERA data are proton target data so that there is no uncertainty from heavy target corrections or deuterium corrections and there is no need to assume that d in the proton is the same as u in the neutron since the d -quark PDF may be extracted from e^+p CC data. Thirdly, the HERA inclusive data give information on the gluon, the Sea and the u - and d -valence PDFs over a wide kinematic region: the low- Q^2 NC e^+p cross-section data are closely related to the low- x Sea PDF and the low- x gluon PDF is derived from its scaling violations; the high- x u - and d -valence PDFs are closely related to the high- Q^2 NC $e^\pm p$, CC e^-p and CC e^+p cross sections, respectively; the difference between the high- Q^2 e^-p and e^+p cross-sections gives the valence shapes down to low x , ($x \sim 10^{-2}$). The HERAPDF1.0 parton distributions are shown in Fig. 1. HERAPDF provides model and parametrisation uncertainties on the PDFs as well as experimental uncertainties. Parametrisation uncertainties come from varying the central form chosen for the parametrisation to allow for more flexible forms, and from varying the starting scale Q_0^2 at which the parametrisation is input and Q^2 evolution begins. The model uncertainties come from varying: the values of the charm and beauty quark masses; the value of the parameter which controls the relative size of the strange compared to the light quarks; and the minimum value of Q^2 for data entering the fit.

When the HERAPDF is used to predict W and Z cross sections at the LHC it is found that the predictions at central rapidity have small total uncertainties $\sim 4\%$. However it is also clear that a major contribution to this uncertainty comes from the model uncertainty on the charm mass value. This can be improved using information from data on $F_2^{c\bar{c}}$.

2.2 Charm data from HERA-I and II running

H1 and ZEUS have also combined their data on $F_2^{c\bar{c}}$ [2]. In Fig. 2 the combined data are compared to the separate data sets which go into the combination. These data are input to the HERAPDF fit together with the inclusive data which were used for HERAPDF1.0. The χ^2 of this fit is sensitive to the value of the charm quark mass. Fig. 3 compares the χ^2 , as a function of this mass, for a fit which includes these data (top left) to that for the HERAPDF1.0 fit (top

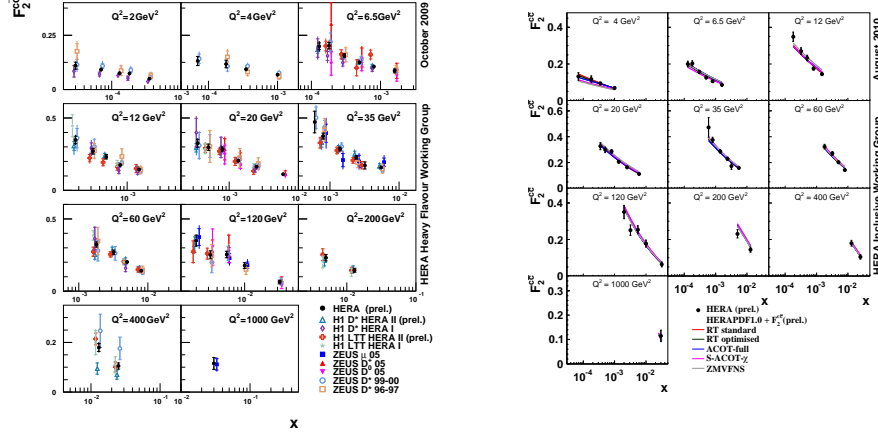


Figure 2: Left: HERA combined data points for $F_2^{c\bar{c}}$, as a function of x in bins of Q^2 , compared to the separate ZEUS and H1 data sets input to the combination. Right: HERA combined data points for $F_2^{c\bar{c}}$ compared to predictions from the HERAPDF fit to these data plus the HERA-I inclusive DIS data, for various different heavy-quark-mass schemes, as specified in the text.

right). However, it would be premature to conclude that the data can be used to determine the charm pole-mass. The HERAPDF formalism uses the Thorne-Roberts (RT) variable-flavour-number (VFN) scheme for heavy quarks. This scheme is not unique, specific choices are made for threshold behaviour. In Fig. 3 (bottom left) the χ^2 profiles for the standard and the optimized versions (optimized for smooth threshold behaviour) of this scheme are compared. The same figure also compares the alternative ACOT VFN schemes and the Zero-Mass VFN scheme. Each of these schemes favours a different value for the charm quark mass, and the fit to the data is equally good for all the heavy quark mass schemes (see Fig. 2 right). However, the Zero-Mass scheme is χ^2 disfavoured. Each of these schemes can be used to predict W and Z production for the LHC and their predictions for W^+ are shown in Fig. 3 as a function of the charm quark mass. If a particular value of the charm mass is chosen then the spread of predictions is as large as $\sim 7\%$. However this spread is considerably reduced $\sim 1\%$ if each heavy quark scheme is used at its own favoured value of the charm quark-mass. Even the Zero-Mass scheme lies only $\sim 2\%$ below the heavy quark schemes. Further details of this study are given in ref. [3].

2.3 Low energy proton beam data from 2007

In 2007 NC e^+p data were taken at two lower values of the proton beam energy in order to determine the longitudinal structure function F_L . Some of the H1 and ZEUS data sets from these runs have now been combined [4] and the results for the NC e^+p cross section are shown in Fig. 4. These data have been input to the HERAPDF fit together with the inclusive data from HERA-I. The resulting parton distributions are compared with those of HERAPDF1.0 in Fig. 4. The low energy data are sensitive to the choice of minimum Q^2 (standard cut $Q^2 > 3.5 \text{ GeV}^2$) for data entering the fit. If a somewhat harder cut, $Q^2 > 5 \text{ GeV}^2$, is made, a steeper gluon distribution results - see Fig. 4, whereas for the HERAPDF1.0 this variation of cuts results in PDFs which lie within the PDF uncertainty bands. This sensitivity is also present if an x cut, $x > 5 \times 10^{-4}$, or a 'saturation inspired' cut, $Q^2 > 0.5 x^{-0.3}$, is made. This sensitivity may indicate the breakdown of the DGLAP formalism at low x [5].

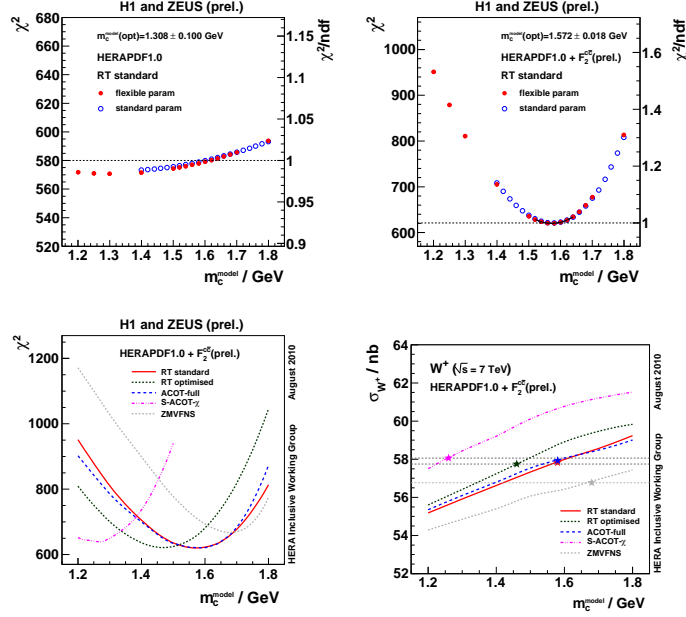


Figure 3: The χ^2 of the HERAPDF fit as a function of the charm mass parameter m_c^{model} . Top left; using the RT-standard heavy-quark-mass scheme, when only inclusive DIS data are included in the fit. Top right; using the RT-standard heavy-quark-mass scheme, when the data for $F_2^{c\bar{c}}$ are also included in the fit. Bottom left; using various heavy-quark-mass schemes, when the data for $F_2^{c\bar{c}}$ are also included in the fit. Bottom right: predictions for the W^+ cross-sections at the LHC, as a function of the charm mass parameter m_c^{model} , for various heavy-quark-mass schemes.

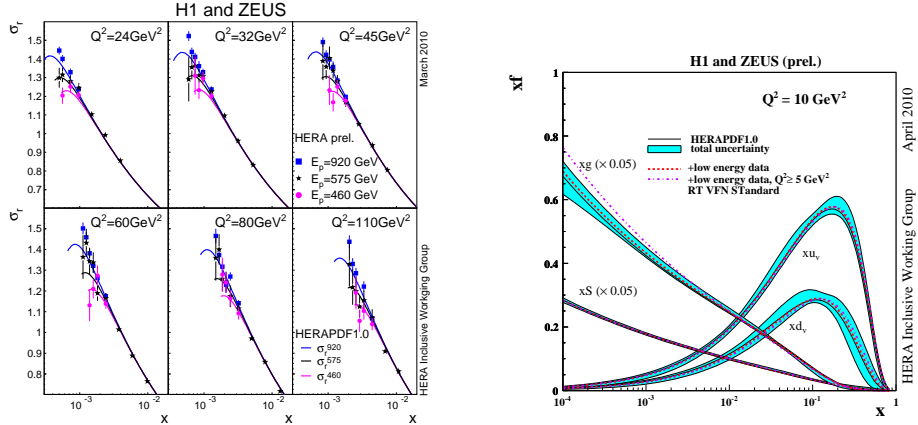


Figure 4: Left: HERA combined data points for the NC e^+p cross-section as a function of x in bins of Q^2 , for three different proton beam energies. Right: Parton distribution functions, xu_v , xd_v , $xS = 2x(\bar{U} + \bar{D})$ and xg at $Q^2 = 10 \text{ GeV}^2$, for HERAPDF1.0 and for a HERAPDF fit which also includes the low-energy proton beam data, with the standard Q^2 cut, $Q^2 > 3.5 \text{ GeV}^2$, and for $Q^2 > 5.0 \text{ GeV}^2$.

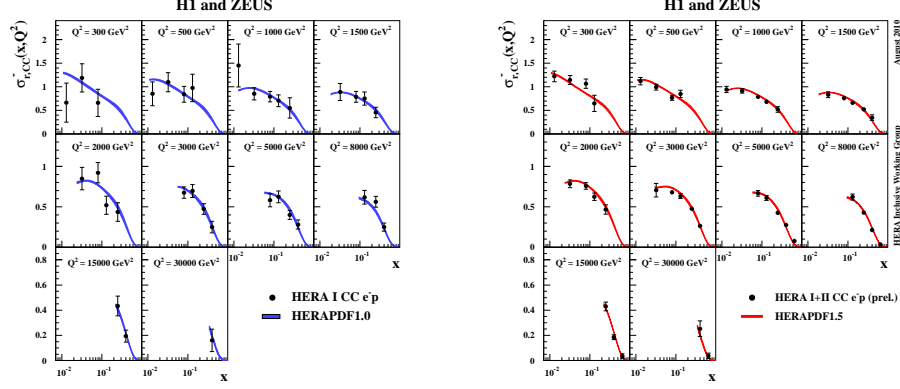


Figure 5: HERA combined data points for the CC e^-p cross-section as a function of x in bins of Q^2 . Left: from the HERA-I run period. Right: from the HERA-I and II run periods. On each plot the HERAPDF fit which includes the corresponding data is illustrated: the HERAPDF1.0 fit on the left hand plot and the HERAPDF1.5 on the right hand plot.

2.4 High- Q^2 data from HERA-II running

Preliminary H1 data on NC and CC e^+p and e^-p inclusive cross-sections and published ZEUS data on NC and CC e^-p and CC e^+p data, from HERA-II running, have been combined with the HERA-I data to yield an inclusive data set with improved accuracy at high Q^2 and high x [6]. The HERA-I data set and the new HERA I+II data sets are compared for CC e^-p data in Fig. 5. This new data set is used as the sole input to a PDF fit called the HERAPDF1.5 which uses the same formalism and assumptions as the HERAPDF1.0 fit [7]. These fits are superimposed on the corresponding data sets in the figure. Fig. 6 (left) shows the combined data for NC $e^\pm p$ cross-sections with the HERAPDF1.5 fit superimposed. The parton distribution functions from HERAPDF1.0 and HERAPDF1.5 are compared in Fig. 6 (right). The improvement in precision at high x is clearly visible. The impact of these improved data on predictions for the LHC may be gauged from Fig. 7 which compares predictions for the W and lepton asymmetries from the HERAPDF1.0 and HERAPDF1.5 fits.

3 Summary

The status of the combinations of HERA data and the PDF fits based on these data have been reviewed. These data form the basis for accurate predictions of LHC cross-sections.

References

- [1] F. D. Aaron *et al.* [H1 and ZEUS Collaboration], JHEP **1001** (2010) 109 [arXiv:0911.0884 [hep-ex]].
- [2] H1 and ZEUS Collaboration, H1prelim-09-171, ZEUS-prel-09-015
- [3] H1 and ZEUS Collaboration, H1prelim-10-143, ZEUS-prel-10-019
- [4] H1 and ZEUS Collaborations, H1prelim-10-043, ZEUS-prel-10-001
- [5] H1 and ZEUS Collaborations, H1prelim-10-044, ZEUS-prel-10-008
- [6] H1 and ZEUS Collaborations, H1prelim-10-141, ZEUS-prel-10-017
- [7] H1 and ZEUS Collaborations, H1prelim-10-142, ZEUS-prel-10-018

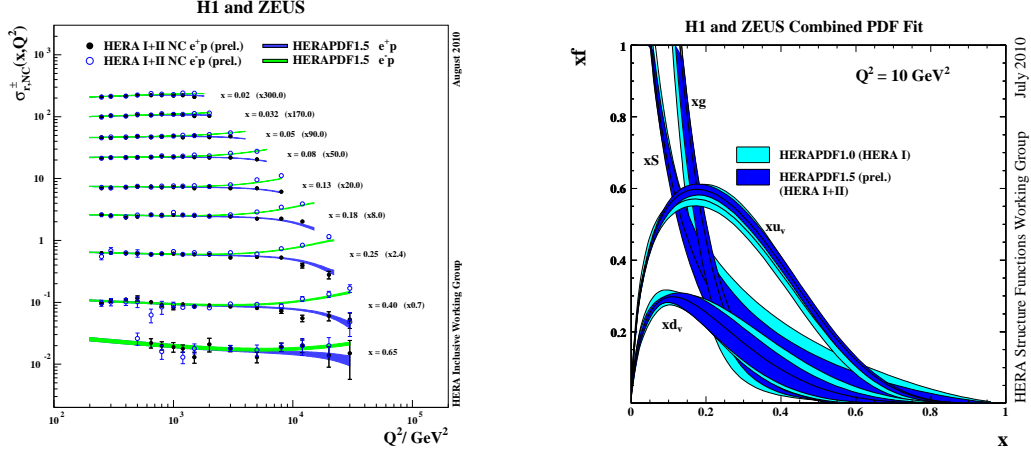


Figure 6: Left: HERA combined data points for the NC $e^\pm p$ cross-sections as a function of Q^2 in bins of x , for data from the HERA-I and II run periods. The HERAPDF1.5 fit to these data is also shown on the plot. Right: Parton distribution functions from HERAPDF1.0 and HERAPDF1.5; xu_v , xd_v , $xS = 2x(\bar{U} + \bar{D})$ and xg at $Q^2 = 10 \text{ GeV}^2$.

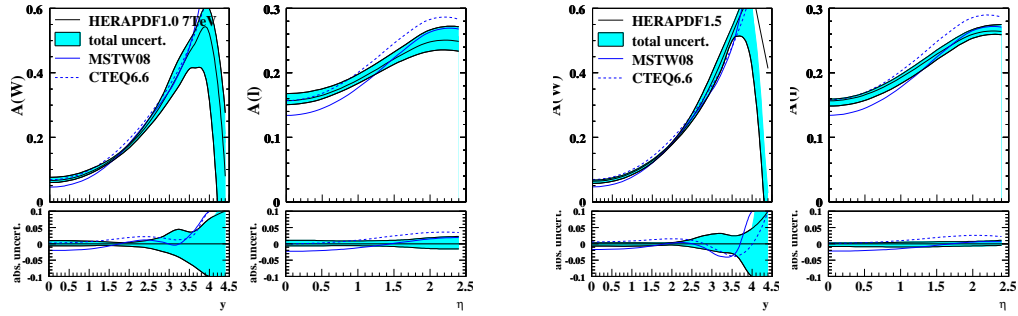


Figure 7: Predictions for the W and lepton asymmetries from HERAPDF1.0 (left) and HERAPDF1.5 (right). The MSTW2008 and CTEQ6.6 PDF predictions are also shown.